Chapter 3 – The Science Content Standards
High School (Grades 9-12): Biology/Life Sciences

INTRODUCTION

As varied as living organisms appear to be, there are basic similarities among their forms and functions. For example, all organisms require an outside source of energy to sustain life processes; all organisms demonstrate patterns of growth and, in many cases, senescence; and the continuity of all species requires reproduction. All organisms are constructed from the same types of macromolecules (proteins, nucleic acids, lipids), and inherit a DNA genome from a parent or parents. DNA is always transcribed to yield RNA, which is translated using a nearly universal genetic code. Expression of specific genes is frequently regulated, and influenced by environmental factors.

Biologists study life at many levels, and the high school biology standards reflect these interests. Organisms are part of an ecosystem, and have complex relationships with other organisms and the physical environment. Ecologists study these populations and communities, and many are deeply interested in the physical and behavioral adaptations of organisms. Evolutionary biologists share these interests, for the "fitness" of an organism is a manifestation of these adaptations. Adaptations are traits subject to the rules of inheritance, so genetics and evolutionary biology are closely allied fields. Physiologists study whole body systems or organs. For example, a neurophysiologist would focus primarily on studying the nervous system. Cell biologists study the details of how cells and organelles work, considering weighty matters such as how cytoskeletal elements segregate chromosomes during mitosis, how proteins are sorted to different compartments of the cell, and how receptors in the cell membrane communicate with factors that regulate gene expression. Many cell biologists also consider themselves to be developmental biologists, molecular geneticists, or biochemists, and indeed there are many connections between all the fields, as well as different ways of viewing life.

Biology texts typically start with a review of chemistry and energetics, and California students will be able to make good use of their focus on physical chemistry in eighth grade. The principles of cellular biology, including respiration and photosynthesis, are usually taught next, followed by molecular and Mendelian genetics. Population genetics and evolution follow naturally from the genetics, and lead into a discussion of diversity of form and physiology. The teaching culminates with ecology, which draws upon each of the preceding topics. It is interesting to note that the teaching comes full circle, because ecology is also a starting point for students in lower elementary school.

STANDARD SET 1: Cell Biology

Background

Our first knowledge of cells came from the work of an English scientist, Robert Hooke, who in 1665 used a primitive microscope to study thin sections of cork and called the box-like cavities he saw “cells.” Anton van Leeuwenhoek later observed one-celled “animalcules” in pond water, but it wasn’t until the 1830s that Theodor Schwann saw cells in cartilage tissue that resembled plant cells. He published the theory that cells were the basic characteristic of life. Virchow, using the work of Schwann and Schleiden, advanced the Cell Theory, presenting the

concept that both plant and animals are made of cells that contain fluid and nuclei, and arise from preexisting cells.

After the cell theory was established, detailed study of cell structure and function was dependent on the improvement of microscopes and techniques for preparing specimens for observation. It is now understood that cells in plants and animals contain both genes to control chemical reactions needed for survival and organelles to perform these reactions. Living organisms may consist of one cell, as in bacteria, or many cells acting in a coordinated and cooperative manner, as in plants, animals, and fungi. All cells have at least three structures in common: genetic material, a cell or plasma membrane, and cytoplasm.

Description of the Standards

1. The fundamental life processes of plants and animals depend on a variety of chemical reactions that occur in specialized areas of the organism's cells. As a basis for understanding this concept:

a. Students know cells are enclosed within semipermeable membranes that regulate their interaction with their surroundings.

The plasma membrane consists of two layers of lipid molecules organized with the polar heads of the molecules forming the outside of the membrane and the non-polar tails forming the interior of the membrane. Protein molecules embedded within the membrane move about relative to one another in a fluid fashion. because of the dynamic nature of the membrane, it is sometimes referred to as the fluid mosaic model of membrane structure.

Cell membranes have three major ways of taking in or regulating the passage of materials into and out of the cell, including simple diffusion, carrier facilitated diffusion, and active transport. Osmosis of water is a form of diffusion. Diffusion does not require the expenditure of chemical bond energy, and the net movement of materials reflects a concentration gradient and/or electrical gradient. Active transport requires energy, either in the form of chemical bond energy or a paired concentration gradient, and permits the net transport or "pumping" of materials against a concentration gradient.

b. Students know enzymes are proteins that catalyze biochemical reactions without altering the reaction equilibrium and the activities of enzymes depend on the temperature, ionic conditions and the pH of the surroundings.

Almost all enzymes are protein catalysts made by living organisms. Enzymes speed up favorable (spontaneous) reactions by reducing the activation energy required for the reaction, but without being consumed in the reactions they promote. To demonstrate the action of enzymes upon a substrate, liver homogenate or yeast can be used as a source of the enzyme catalase and hydrogen peroxide as the substrate. The effect of various environmental factors such as pH, temperature, and substrate concentration on the rate of reaction, or turnover rate, can be investigated. These investigations should encourage student observation, recording of qualitative and quantitative data, and graphing and interpretation of data.

c. Students know how prokaryotic cells, eukaryotic cells (including those from plants and animals), and viruses differ in complexity and general structure.

All living cells are divided into one of two groups based on their cellular structure. Prokaryotes have no membrane-bound organelles and are represented by the Kingdom Monera, which in modern nomenclature is subdivided into the Eubacteria and Archaea. Eukaryotes have a complex internal structure that allows thousands of chemical reaction to proceed simultaneously in various organelles. Viruses are not cells, but consist only of a protein coat surrounding a strand of genetic material, either ribonucleic acid (RNA) or deoxyribonucleic acid (DNA).

d. Students know the central dogma of molecular biology outlines the flow of information from transcription of ribonucleic acid (RNA) in the nucleus to translation of proteins on ribosomes in the cytoplasm.

DNA contains the genetic information for encoding proteins, and is found in the nucleus of eukaryotes. The DNA sequence specifying a specific protein is copied (transcribed) into mRNA, which then carries this message out of the nucleus to the ribosomes located in the cytoplasm. The mRNA message is then translated or converted into the protein originally coded for by the DNA.

e. Students know the role of the endoplasmic reticulum and Golgi apparatus in the secretion of proteins.

There are two types — rough and smooth — of endoplasmic reticulum (ER), both of which are systems of folded sacs and interconnected channels. Rough ER synthesizes proteins, and smooth ER is involved in the modification or detoxification of lipids. Rough ER produces new proteins including membrane proteins. Those proteins to be exported from the cell are moved to the Golgi apparatus for modification, packaged in vesicles, and transported to the plasma membrane for secretion.

f. Students know usable energy is captured from sunlight by chloroplasts and is stored through the synthesis of sugar from carbon dioxide.

Photosynthesis is a complex process in which visible sunlight is converted into chemical energy in carbohydrate molecules. It occurs within chloroplasts, and specifically within the thylakoid membrane (light dependent reaction) and the stroma (light independent). During the light dependent reaction, water is broken down, light energy is converted to chemical bond energy generating ATP (adenosine triphosphate), $NADPH + H^+$, and oxygen gas. During the light independent reaction (Calvin cycle), carbon dioxide, ATP, and $NADPH + H^+$ react, forming phosphoglyceraldehyde, which is then converted into sugars. With the use of a microscope of appropriate magnification, students can see the chloroplasts in plant cells (e.g., lettuce, onion) and photosynthetic protists(e.g., Euglena).

Students can prepare slides of these cells themselves, a good opportunity to see the necessity for well-made thin sections and correct staining procedures. Commercially prepared

slides are also available. By observing prepared leaf cross sections under a microscope, students can see how a leaf is organized structurally and think about the access of cells to light and carbon dioxide during photosynthesis. The production of oxygen as a product of photosynthesis can be demonstrated and measured quantitatively with a volumeter, which can collect oxygen gas from the illuminated leaves of an aquatic plant such as Elodea. The effects of various illumination intensities can be demonstrated by varying the distance between the light source and the plant. It is important to place a heat sink, such as a beaker of water, between the plant and light source to eliminate heat as a factor.

g. Students know the role of the mitochondria in making stored chemical-bond energy available to cells by completing the breakdown of glucose to carbon dioxide.

Mitochondria consist of a matrix where three carbon fragments originating from carbohydrates are broken down and cristae where ATP production occurs. Cell respiration occurs in a series of reactions in which fats, proteins, and carbohydrates, mostly glucose, are broken down to produce carbon dioxide, water, and energy. Some of the energy from cell respiration is converted into ATP, which powers most cell activities.

h. Students know most macromolecules (polysaccharides, nucleic acids, proteins, lipids) in cells and organisms are synthesized from a small collection of simple precursors.

Many of the large carbon compound molecules necessary for life (e.g., polysaccharides, nucleic acids, proteins, and lipids) are polymers of smaller monomers. Polysaccharides are composed of monosaccharides, proteins are composed of amino acids, lipids are composed of fatty acids, glycerol and other components, and nucleic acids are composed of nucleotides.

i Students know how chemiosmotic gradients in the mitochondria and chloroplast store energy for ATP production.*

Enzymes called ATP synthase, located within the thylakoid membranes in chloroplasts and cristae membranes in mitochondria, synthesize most ATP within cells. The thylakoid and cristae membranes are impermeable to protons except at pores that are coupled with the ATP synthase. The potential energy of the proton concentration gradient drives ATP synthesis as the protons move through the ATP synthase pores. The proton gradient is established by energy furnished by a flow of electrons passing through the electron transport system, located within these membranes.

j. Students know how eukaryotic cells are given shape and internal organization by a cytoskeleton or cell wall or both.*

The cytoskeleton, which gives shape to and organizes eukaryotic cells, is composed of fine protein threads called microfilaments and thin protein tubes called microtubules. Cilia and flagella are composed of microtubules arranged in the 9+2 arrangement, in which nine pairs of microtubules surround two singlet microtubules. The rapid assembly and disassembly of microtubules and microfilaments along with their capacity to slide past one another enables cells to move, as observed in white blood cells and amoeba, and also accounts for organelle

movement within the cell. Students can observe prepared slides of plant mitosis in onion root tip to see the microtubules that make up the spindle apparatus. Prepared slides of white fish blastula reveal animal spindle apparatus and centrioles, both of which are composed of microtubules.

STANDARD SET 2: Genetics (Meiosis And Fertilization)

Background

Students should know that organisms reproduce offspring of their own kind, and that organisms of the same species resemble each other. They have been introduced to the idea that some characteristics can be passed from parents to offspring, and that individual variations appear among offspring as well as in the broader population. Understanding genetic variation requires mastery of the fundamentals of sex cell formation, and the steps to reorganize and redistribute genetic material during defined stages in the cell cycle.

Students should understand the difference between asexual cell reproduction (mitosis) and the formation of male or female gamete cells (meiosis). Sexual reproduction initially requires the production of haploid eggs and haploid sperm, a process occurring in humans within the female ovary and the male testis. These haploid cells unite in fertilization and produce the diploid zygote, or fertilized cell.

The mechanisms involved in synapsis and movement of chromosomes during meiosis bring about both the division of the chromosome numbers for the production of the haploid male or female gamete cells from the original diploid parent cell and different combinations of parental genes. The exchange of chromosomal segments between homologous chromosomes (crossing over) revises the association of genes on the chromosomes and contributes to increased diversity. Any change in genetic constitution through mutation, crossing over, or chromosome assortment during meiosis promotes genetic variation in a population.

Description of the Standards

2. Mutation and sexual reproduction lead to genetic variation in a population. As a basis for understanding this concept:

a. Students know meiosis is an early step in sexual reproduction in which the pairs of chromosomes separate and segregate randomly during cell division to produce gametes containing one chromosome of each type.

Haploid gamete production through meiosis involves two cell divisions. During meiosis prophase I the homologous chromosomes and the homologues are paired, which abets the exchange of chromosome parts through breakage and reunion. The second meiotic division parallels the mechanics of mitosis except that it is not preceded by a round of DNA replication, so that the cells end up with the haploid number of chromosomes. Four haploid nuclei result from the two divisions that characterize meiosis, and each of the four resulting cells have different chromosomal constituents (components). In the male, all four beome sperm cells. In the female, only one becomes an egg, while the other three remain small degenerate polar bodies and cannot be fertilized. Chromosome models can be constructed and used to illustrate the segregation taking place during the phases of mitosis (covered initially in Grade 7, Standard Set

1e) and meiosis. Commercially available optical microscope slides also show cells captured in mitosis (onion root tip) or meiosis (Ascaris blastocyst cells), and computer and video animations are also available.

b. Students know only certain cells in a multicellular organism undergo meiosis.

Only special diploid cells, called spermatogonia in the testis of the male and oogonia in the female ovary, undergo meiotic divisions to produce the haploid sperm and haploid eggs.

c. Students know how random chromosome segregation explains the probability that a particular allele will be in a gamete.

The steps in meiosis involve random chromosome segregation, which accounts for the probability that a particular allele will be packaged in any given gamete. This allows genetic predictions based on laws of probability which pertain to genetic sortings. Students can create a genetic chart and mark alternate traits on chromosomes, one expression coming from the mother and another expression coming from the father. Students can be shown that alignments of the chromosomes are controlled by chance (are random) and that separation (segregation) of chromosomes during karyokinesis results in the random sequestering of different combinations of chromosomes..

d. Students know new combinations of alleles may be generated in a zygote through the fusion of male and female gametes (fertilization).

Once gametes are formed, the second half of sexual reproduction can take place, which involves the reconstitution of a diploid organism from two haploid parts. When a sperm is coupled with an egg, a fertilized egg (zygote) is produced which contains the combined genotypes of the parents to produce a new allelic composition for the progeny. Genetic charts can be used to illustrate how new combinations of alleles may be generated in a zygote through the events of meiosis and the chance union of gametes. Students should be able to read the genetic diploid karyotype, or chromosomal makeup, of a fertilized egg, and compare the allelic composition of progeny with the genotypes and phenotypes of the parents

e. Students know why approximately half of an individual's DNA sequence comes from each parent.

Chromosomes are composed of DNA and protein. Genes are defined as segments of DNA that code for either a polypeptide or a protein. During fertilization, half the chromosomes (DNA) come from the gamete of one parent and the other half come from the gamete of the other parent.

f. Students know the role of chromosomes in determining an individual's sex.

The normal human somatic cells contain 46 chromosomes, or 23 pairs of homologous chromosomes of which 22 pairs are autosomes Females usually carry two X chromosomes, while males possess one X chromosome and a smaller homologue called y. Combinations of

these chromosomes in the zygote determine the sex of the progeny.

g. Students know how to predict the possible combinations of alleles in a zygote from the genetic makeup of the parents.

By knowing the genetic makeup of the parents, it is possible to derive the possible gamete genomes that can be produced by these potential parents. From this, it is possible to recombine the genetic contributions from each parent to determine possible examples of zygotic allelic make-up.

STANDARD SET 3: Genetics (Mendel's Laws)

Background

Plant and animal breeding have been active technologies for thousands of years, but the science of heredity is linked to the name of genetics pioneer Gregor Mendel. He studied phenotypic traits of various plants, especially peas. From their appearance in different generations of growth, he was able to infer their genotypes and to speculate about the genetic make-up and method of transfer of the hereditary units from one generation to the next. Predictions of probable progeny phenotypes based upon various parental genetic crosses may now be made using probability analyses. The genetic basis for Mendel's laws of segregation and independent assortment are apparent from genetic outcomes of crosses.

Description of the Standards

3. A multicellular organism develops from a single zygote, and its phenotype depends on its genotype, which is established at fertilization. As a basis for understanding this concept:

a. Students know how to predict the probable outcome of phenotypes in a genetic cross from the genotypes of the parents and mode of inheritance (autosomal or X-linked, dominant or recessive).

Monohybrid crosses including autosomal dominant alleles, autosomal recessive alleles, incomplete dominant alleles and X-linked alleles, may be used to indicate the parental genotypes and phenotypes. The possible gametes derived from each parent are based on genotypic ratios, and may be used to predict possible progeny. The predictive (probabilistic) methods for determining the outcome of genotypes and phenotypes in a genetic cross can be introduced using Punnett Squares and probability mathematics. Teachers should review the process of writing genotypes and help students translate genotypes into phenotypes. Emphasis should be placed on dominant, recessive, and incomplete dominance as the students advance to an explanation of monohybrid crosses illustrating human conditions characterized by autosomal recessive alleles such as albinism, cystic fibrosis, Tay Sachs, and phenylketonuria (PKU). Contrast these disorders to those produced by possession of just one autosomal dominant allele, conditions such as Huntington's Disease, dwarfism, and neurofibromatosis. This basic introduction can be followed with examples of incomplete dominance such as seen in the comparisons of straight, curly, and wavy hair, or the expression of intermediate flower colors in snapdragon plants.

Sex-linked characteristics that are only found on the X chromosome should also be considered, and students should reflect on how this mode of transmission can cause the exclusive or near-exclusive appearance in males of color blindness, hemophilia, fragile-X syndrome, and sex-linked muscular dystrophy.

b. Students know the genetic basis for Mendel's laws of segregation and independent assortment.

Mendel deduced that for each characteristic, an organism inherits two genes, one from each parent. When the two alleles differ, the dominant allele is expressed while the recessive allele remains hidden. Two genes or alleles separate (segregate) during gamete production in meiosis resulting in sorting of alleles into separate gametes (the law of segregation). Students can be shown how to diagram Mendel's explanation for how a trait present in the parental generation can appear to vanish in the first filial "F1" generation of a monohybrid cross, and then reappear in the following "F2" generation. Students should be told that alternate versions of a gene are called alleles. Students should understand Mendel's deduction that for each character, an organism inherits two genes, one from each parent. From this point they should realize that if the two alleles differ, the dominant allele, if there is one, is expressed while the recessive allele remains hidden. Students should recall that the two genes or alleles separate (segregate) during gamete production in meiosis and that this sorting of alleles into separate gametes is the basis for the law of segregation. This applies most accurately when genes reside on separate chromosomes that segregate out at random, and often does not apply or is a poor predictor for combinations and frequencies of genes that reside on the same chromosome. Students can study expository text that describes Mendel's logic, and build models to illustrate the Laws of Segregation and Independent Assortment.

c. Students know how to predict the probable mode of inheritance from a pedigree diagram showing phenotypes.*

Students should be taught how to use a phenotype pedigree diagram to predict inheritance mode.

d. Students know how to use data on frequency of recombination at meiosis to estimate genetic distances between loci and to interpret genetic maps of chromosomes.*

Students should be able to interpret genetic maps of chromosomes and manipulate genetic data by standard techniques to relate recombination at meiosis to estimate genetic distances between loci.

STANDARD SET 4: Genetics (Molecular Biology)

Background

All cells contain DNA as their genetic material. The role of DNA in organisms is two-fold, first to store and transfer genetic information from one generation to the next, and second to express that genetic information in the synthesis of proteins. By controlling protein synthesis,

DNA controls the structure and function of all cells. Depending on the complexity of an organism, there may be several hundred to more than several thousand proteins as part of its makeup. Proteins are composed of a sequence of amino acids linked by peptide bonds (Grades 9-12, Chemistry, Standard Set 10c). The identity, number, and sequence of the amino acids in a protein gives each protein its unique structure and function. Twenty types of amino acids commonly are employed in proteins, and each can appear many times in a single protein molecule. The proper sequence of amino acids in a protein is translated from an RNA sequence that is itself encoded in the DNA.

Description of the Standards

4. Genes are a set of instructions encoded in the DNA sequence of each organism that specify the sequence of amino acids in proteins characteristic of that organism. As a basis for understanding this concept:

a. Students know the general pathway by which ribosomes synthesize proteins, using tRNA's to translate genetic information in mRNA.

DNA does not leave the cell nucleus, but mRNA (messenger RNA), complementary to DNA, carries the coded protein message from DNA to the ribosomes (transcription) in the cytoplasm. Freely floating amino acids within the cytoplasm are bonded to specific tRNAs (transfer RNAs) that then transport the amino acid to the mRNA now located on the ribosome. As a ribosome moves along the mRNA strand, each mRNA codon, or sequence of three nucleotides specifying the insertion of a particular amino acid, is paired in sequence with the anticodon of the tRNA that recognizes the sequence. Each amino acid is added, in turn, to the growing polypeptide at the specified position. After learning about transcription and translation by careful study of expository texts, students can simulate the processes on paper or with representative models. Computer software and commercial videos are available that illustrate animated sequences of transcription, translation, and protein synthesis.

b. Students know how to apply the genetic coding rules to predict the sequence of amino acids from a sequence of codons in RNA.

The sequence of amino acids in protein is provided by the genetic information found in DNA. In prokaryotes, mRNA is a transcript copied from one strand of the DNA code for a specific protein sequentially, three nucleotides at a time. In eukaryotes, the initial RNA transcript, while in the nucleus, is composed of exons, sequences of nucleotides that carry useful information for protein synthesis, and introns, sequences that do not. Prior to leaving the nucleus, the initial transcript is processed to remove introns and splice together exons. The processed transcript, then properly called mRNA and carrying the appropriate codon sequence for a protein, is transported from the nucleus to the ribosome for translation. Each mRNA has sequences that are decoded three nucleotides at a time, and these are called codons. Each codon specifies addition of a single amino acid to a growing polypeptide chain. A start codon signals the beginning of the sequence of codons to be translated and stop codon ends the sequence to be translated into protein. Students can write out mRNA sequences with start and stop codons from a given DNA sequence, and use a table of the genetic code to predict the primary

sequences of proteins.

c. Students know how mutations in the DNA sequence of a gene may or may not affect the expression of the gene or the sequence of amino acids in the encoded protein.

Mutations are permanent changes in the sequence of nitrogen bases in DNA (see Grades 9 to 12, Biology, Standard Set 5a for details on DNA structure and nitrogen bases). Mutations occur when base pairs are incorrectly matched (e.g., "A" bonded to "C" rather than "A" bonded to "T") and can but usually do not cause improvement in the product coded by the gene. Inserting or deleting base pairs in an existing gene can cause a mutation by changing the codon reading frame used by a ribosome. Mutations that occur in somatic, or non-germ, cells are often not detected because they cannot be passed on to offspring. They may, however, give rise to cancer or other undesirable cellular changes. Mutations in the germline can produce functionally different proteins that cause such genetic diseases as Tay Sachs, sickle cell anemia, and Duchenne muscular dystrophy.

d. Students know specialization of cells in multicellular organisms is usually due to different patterns of gene expression rather than to differences of the genes themselves.

Gene expression is a process whereby a gene codes for a product, usually a protein, through the processes of transcription and translation. Nearly all cells in an organism contain the same DNA, but each cell transcribes only that portion of DNA containing the genetic information for proteins required at that specific time by that specific cell. The remainder of the DNA is not expressed. Specific types of cells may produce specific proteins that are unique to that type of cell.

e. Students know proteins can differ from one another in the number and sequence of amino acids.

Protein molecules vary from about 50 to 3000 amino acids in length. The types, sequences, and numbers of amino acids used all determine the type of protein produced.

f Students know why proteins having different amino acid sequences typically have different shapes and chemical properties.*

The 20 different protein-making amino acids have the same basic structure: an amino group, an acidic (carboxyl) group, and an R, or radical group (Grades 9 to 12, Chemistry, Standard Set 10). The protein is formed by the amino group of one amino acid linking to the carboxyl group of another amino acid. This bond, called the peptide bond, is repeated to form long molecular chains with the R groups attached along the polymer backbone. The properties of these amino acids vary from one another by virtue of both the order and chemical properties of these R groups. Typically, the long protein molecule folds upon itself, creating a three-dimensional structure related to its function. Structure, for instance, may allow a protein to be a highly specific catalyst, or enzyme, able to position and hold other molecules. The R group of an amino acid consists of atoms that may include carbon, hydrogen, nitrogen, oxygen and sulfur, depending on the amino acid. Amino acids containing sulfur sometimes plays an important role

of cross-linking and stabilizing polymer chains. Because of their various R groups, different amino acids vary in their chemical and physical properties, such as solubility in water, electrical charge, and size. These differences are reflected in the unique structure and function of each type of protein.

STANDARD SET 5: Genetics (Biotechnology)

Background

Long before scientists identified DNA as the genetic material of cells, much was known about inheritance and the relationships between various characteristics likely to appear from one generation to the next. However, to understand clearly how the genetic composition of cells changes, it is necessary for students to understand the structure and activity of nucleic acids. DNA recombination or genetic recombination occurs naturally in sexual reproduction, viral infection and bacterial transformation. These natural events change the genetic makeup of organisms, and provide the raw materials for evolution. Natural selection determines the "usefulness" of the recombinants. Recombinant DNA technology involves the recombination of specific pieces of DNA in the laboratory to achieve a specific goal. The scientist, rather than natural selection, then determines the usefulness of the recombinant DNA created.

Description of the Standards

5. The genetic composition of cells can be altered by incorporation of exogenous DNA into the cells. As a basis for understanding this concept:

a. Students know the general structures and functions of DNA, RNA, and protein.

Nucleic acids are polymers composed of monomers called nucleotides. Each nucleotide consists of three subunits, a 5-carbon pentose sugar, a phosphoric acid group, and one of four nitrogen bases – for DNA these are **A**denine, **G**uanine, **C**ytosine or **T**hymine. DNA and RNA differ in a number of major ways. A DNA nucleotide contains a deoxyribose sugar whereas RNA contains ribose sugar. The nitrogen bases in RNA are the same as DNA except thymine is replaced by uracil. RNA consists of only one strand of nucleotides rather than two as in DNA. The DNA molecule consists of two strands, twisted around each other into a double helix resembling a ladder twisted around its long axis. The outside or uprights of the ladder are formed by the two sugar-phosphate backbones. The rungs of the ladder are composed of pairs of nitrogen bases, one extending from each upright. In DNA, these nitrogen bases always pair so that T pairs with A and G pairs with C. This pairing accounts for the ability of DNA to act as a template for its own replication. RNA exists in many structural forms, many of which play different roles in protein synthesis. The mRNA form serves as a template during protein synthesis, and its codons are recognized by aminoacylated tRNAs. rRNA, along with protein, make up the structure of the ribosome. Proteins are polymers composed of amino acid monomers (see Grades 9 to 12, Chemistry, Standard Set 10). Different types of proteins function as enzymes, transport molecules, hormones, structural components of cells, and antibodies, that fight infection. Most cells in an individual organism carry the same set of DNA instructions, but don't use the entire DNA set all the time. Only a small amount of the DNA,

appropriate to the function of that cell, is expressed. Genes are, therefore, turned on or turned off as needed by the cell, and the products coded by these genes are produced only when required.

b. Students know how to apply base-pairing rules to explain precise copying of DNA during semi-conservative replication and transcription of information from DNA into mRNA.

Enzymes initiate DNA replication by "unzipping" or unwinding the double helix to separate the two parental strands. Each strand acts as a template for the formation of a complementary daughter strand of DNA. The new daughter strands are formed by the addition of new nucleotides that are complementary to the bases of the nucleotides on the parental strands. The order of the nucleotides in the newly forming daughter strands is dictated by the nucleotide sequence of the parental strand. When one parental strand is conserved and joins a newly synthesized complementary strand to form the new double helix, the process is referred to as semi-conservative replication. RNA is produced from DNA when a section of DNA (containing the nucleotide sequence required for the production of a specific protein) is transcribed. Only the template side of the DNA is copied. RNA then leaves the nucleus and travels to the cytoplasm where protein synthesis takes place. Students may visualize DNA by constructing models, and can simulate semi-conservative replication by tracing the synthesis of the leading and lagging strands. The critical principles to teach with this activity are that two double-stranded DNA strands are the product of synthesis, that the process was semi-conservative, that the anti-parallel orientation of the strands requires repeated re-initiation on the lagging strand, and that the only information used during synthesis was specified by the base-pairing rules.

c. Students know how genetic engineering (biotechnology) is used to produce novel biomedical and agricultural products.

Recombinant DNA contains DNA from two or more different sources. Bacterial plasmids and viruses are the two most common vectors, or means, by which recombinant DNA is introduced into a host cell. Restriction enzymes provide the means by which researchers cut DNA at desired locations to provide DNA fragments with "sticky ends". Genes, once identified, can be amplified by cloning or polymerase chain reactions, both of which produce large numbers of copies. The recombinant cells are then grown in large fermentation vessels and their products are extracted from the medium and purified. Genes for human insulin, human growth hormone, blood clotting factors and many other products have been identified and introduced into bacteria or other microorganisms that are then cultured for commercial production. Agricultural applications of this technology have included the identification and insertion of genes to increase productivity of food crops and animals, resistance to certain pests and herbicides, robustness in the face of harsh environmental conditions, and resistance to various viruses.

Students can model the recombinant DNA process using paper models to represent eukaryotic cDNA, the activity of different restriction enzymes, and ligation into plasmid DNA containing an antibiotic resistance gene and origin of DNA replication. The modeled DNA sequences can be manipulated using scissors (restriction enzymes) and tape (DNA ligase). If both strands are modeled on a paper tape, students can visualize how many restriction enzymes

make staggered cuts that generate sticky ends, and how the ends must be matched during ligation.

d. Students know how basic DNA technology (restriction digestion by endonucleases, gel electrophoresis, ligation, and transformation) is used to construct recombinant DNA molecules.*

Recombinant DNA technology involves the isolation and exchange of DNA between organisms for a specific human purpose. The desired gene is usually identified and extracted by cutting the DNA into fragments with restriction enzymes or "endonucleases". Restriction enzymes typically cut palindromic portions of DNA, which read the same forward and backward, in ways that form “sticky” complementary ends. DNA from different sources, but with complementary sticky ends, can be joined together by the enzyme DNA ligase, thus forming recombinant DNA. DNA fragments of varying lengths can be separated from one another by gel electrophoresis. The particles are moved through an agarose gel propelled by an electric current. Depending on the size and electrical charge of the particles, they will move at different rates through the gel and thus form bands of particles of similar size and charge. With appropriate staining, the various DNA fragments can then be visualized and removed for further analysis or recombination.

e. Students know how exogenous DNA can be inserted into bacterial cells to alter their genetic makeup and support expression of new protein products.*

Bacteria can be induced to take up recombinant plasmids, a process called DNA transformation, and the plasmid is replicated as the bacteria reproduce. Recombinant bacteria can be grown to obtain billions of copies of the recombinant DNA. Commercially available kits containing all of the necessary reagents, restriction enzymes, and bacteria are available for plasmid DNA transformation experiments. Although the reagents and equipment can be expensive, various California corporations and universities have programs that can make the cost more affordable, sometimes providing reagents and loaning equipment. Students should know that DNA transformation is a natural process, and that horizontal DNA transfer is common in the wild. While the technology allows the process to be put to good use, it is not "unnatural". Selective breeding of pets and agricultural crops is another example of how genetic makeup has been manipulated by humans.

STANDARD SET 6: Ecology

Background

Ecology involves the study of relationships among living organisms, and their interactions with the physical environment. These relationships are in a constant state of flux, and even small changes can cause effects throughout the ecosystem. In grades 9 to 12, it is important to think of ecology in terms of changing relationships among the components of an ecosystem. It is also important to recognize that humans are participants in these ecosystem relationships and not just observers. A goal of classroom teaching should be to develop a strong

scientific understanding of ecology that will serve as the basis for making informed and valid decisions.

Description of the Standards

6. Stability in an ecosystem is a balance between competing effects. As a basis for understanding this concept:

a. Students know biodiversity is the sum total of different kinds of organisms and is affected by alterations of habitats.

Biodiversity refers to the collective variety of living organisms in an ecosystem. It is influenced by alterations in habitat, such as, but not limited to), climatic changes, fire, flood, and invasion by organisms from another system. The more biodiversity an ecosystem contains, the more stable and resilient it is to alteration. The best way to learn about ecology is to master the principles of the subject by careful study and then to make first-hand observations of ecosystems in action over time. While field trips are the ideal way to implement this, and should be encouraged, even career scientists often use models to study ecology. Local ecologists from government, private industry, or university programs may also be willing to serve as guest speakers in the classroom. Participation in the Internet's many "virtual windows" that show actual ecological experiments can also help students understand the scientific basis of ecology.

b. Students know how to analyze changes in an ecosystem resulting from changes in climate, human activity, introduction of non-native species, or changes in population size.

Analysis of change can help people describe and understand what is happening in a natural system and, to some extent, to control or influence that system. Understanding different kinds of change can help improve predictions of what will happen next. Changes in ecosystems often manifest themselves in predictable patterns of climate, seasonal reproductive cycles, population cycles, and migrations. However, unexpected disturbances associated with human intervention or the introduction of a new species, for example, may destabilize the often complex and delicate balance in an ecosystem.

Analyzing ecosystem changes can require complex methods and techniques because variation is not necessarily simple and may be interrelated with changes or trends in other factors. Rates and patterns of change, including trends, cycles and irregularities, are essential features of the living world and are useful indicators of change that can provide data for analysis. Often it is important to analyze change over time, called longitudinal analysis.

c. Students know how fluctuations in population size in an ecosystem are determined by the relative rates of birth, immigration, emigration, and death.

Fluctuations in population size are often difficult to measure directly, but may be estimated by measuring the relative rates of birth, death, immigration, and emigration in a population. The number of deaths and emigrations over time will decrease a population's size, while the number of births and immigrations over time will increase it. Comparing death and

emigration rates with birth and immigration rates will determine if the population shows a net growth or decline over time.

d. Students know how water, carbon, and nitrogen cycle between abiotic resources and organic matter in the ecosystem and how oxygen cycles through photosynthesis and respiration.

Living things depend on non-living things for life. At the organism level they depend upon natural resources and at the molecular level they depend on chemical cycles. Water, carbon, nitrogen, phosphorus and other elements are recycled back and forth between organisms and their environments. Water, carbon and nitrogen are all necessary for the existence of life. These chemicals are incorporated into plants (producers) by photosynthesis and nitrogen fixation, and used by animals (consumers) for food and protein synthesis. Chemical recycling occurs through respiration, the excretion of waste products, and, of course, the death of organisms.

e. Students know a vital part of an ecosystem is the stability of its producers and decomposers.

An ecosystem's producers (plants and photosynthetic microorganisms) and decomposers (fungi and microorganisms) are primarily responsible for the productivity and recycling of organic matter, respectively. Conditions that threaten the stability of producer and decomposer populations jeopardize the energy availability and matter recycling capability for the rest of the biological community. To study the interaction between producers and decomposers, students can set up a closed or restricted ecosystem, such as a worm farm, composting system, terrarium, or aquarium.

f. Students know at each link in a food web some energy is stored in newly made structures but much energy is dissipated into the environment as heat. This dissipation may be represented in an energy pyramid.

The energy pyramid illustrates how stored energy is passed from one organism to another. At every level in a food web, energy is used metabolically by an organism for survival and growth, but much is released as heat, usually about 90 percent. At every link in a food web, energy is transferred to the next level, but typically only 10 percent of the energy from the previous level is passed on to the consumer.

g. Students know how to distinguish between the accommodation of an individual organism to its environment and the gradual adaptation of a lineage of organisms through genetic change.*

Living organisms adapt to changing environments in ways that may involve behavioral modifications and physical, or genetic, changes. Genetic and behavioral adaptations are sometimes difficult to identify or distinguish without studying the organism over a long period of time. Physical changes are slow to develop in most organisms, requiring careful measurements over many years. Examining fossil ancestors of the organism may help provide clues for

detecting adaptation through genetic change. Genetic change can institute behavioral changes, making it all the more complicated to determine if a change is solely a behavioral accommodation to environmental change. Utilizing print and online resources in library media centers, students can research the effects of encroaching urbanization on undeveloped land, and consider the effects on specific species such the coyote (not endangered) and the California condor (endangered). Such examples can illustrate how some organisms adapt to their environments by learned changes in behavior, while others are unsuccessful in learning survival skills. Over long periods of time, organisms can also adapt to changing environments by genetic changes. Such changes may be difficult to recognize because long periods of time must elapse before the changes can be recognized. Studies of the origins of desert pup fish or blind cave fish may help students understand how gradual genetic changes result in adaptations to habitat changes.

STANDARD SET 7: Evolution (Population Genetics)

Background (Standard Sets 7 and 8)

In high school, students should be ready to explore and understand the concept of biological evolution from its basis in genetics. The synthesis of genetics, and later molecular biology, with the Darwin-Wallace theory of natural selection both validated the mechanism of evolution and extended its scientific impact. It is important for students to understand that the human species is impacted by the same evolutionary mechanisms that have affected the rest of the living world.

Students need to understand that a theory in science is not merely a hypothesis or a guess, but rather a unifying explanation of observed phenomena. Charles Darwin's theory of the origin of species by natural selection is such an explanation. Even though biologists continue to test the boundaries of this theory today, their investigations have not succeeded in finding credible evidence to refute the theory. Scientists have also had many opportunities to demonstrate the gradual evolution of populations in the wild, and in controlled laboratory settings. As more populations of organisms are studied at the level of DNA sequence, and as the fossil record improves, the understanding of species divergence has become clearer.

Description of the Standards

7. The frequency of an allele in a gene pool of a population depends on many factors and may be stable or unstable over time. As a basis for understanding this concept:

a. Students know why natural selection acts on the phenotype rather than the genotype of an organism.

Natural selection works directly on the expression or appearance of an inherited trait, the phenotype, rather than on the gene combination that produces it, the genotype. The influence of a dominant allele for a trait over a recessive one in the genotype determines the resulting phenotype on which natural selection acts.

b. Students know why alleles that are lethal in a homozygous individual may be carried in a heterozygote and thus maintained in a gene pool.

Two types of allele pairings can occur in the genotype; homozygous (pairing two of the same alleles, whether dominant, co-dominant, or recessive), and heterozygous, (pairing of two different alleles).- Recessive lethal alleles (e.g., Tay-Sachs) will, by definition, only cause death of the homozygous recessive individual. Healthy heterozygous individuals will also contribute the masked recessive gene to the population's gene pool allowing it to persist.

c. Students know new mutations are constantly being generated in a gene pool.

Mutation is an important source of genetic variation within a gene pool. These random changes take the form of nucleotide additions, deletions, substitutions, and chromosomal rearrangements. Many of these mutations are minor and neutral in effect, being neither favorable nor unfavorable to survival and reproduction. Others may be either beneficial or harmful. The important principle is that genetic diseases or unwanted traits cannot be eliminated from a population by culling or selective breeding. The trait constantly reappears in the population in the form of new, spontaneous mutations.

d. Students know variation within a species increases the likelihood that at least some members of a species will survive under changed environmental conditions.

As environmental factors change, natural selection of adaptive traits must also be realigned. Variation within a species stemming either from mutation or genetic recombination broadens the opportunity for that species to adapt to the change, increasing the probability that at least some members of the species will be suitably adapted to the new conditions. Genetic diversity promotes survival of a species in the event of significant environmental change, while sameness can mean vulnerability that could lead to extinction.

e. Students know the conditions for Hardy-Weinberg equilibrium in a population and why these conditions are not likely to appear in nature.*

The principle of Hardy-Weinberg equilibrium, derived in 1908, asserts that the genetic structure of a nonevolving population remains constant over the generations. If mating in a large population occurs randomly without the influence of natural selection, the migration of genes from neighboring populations or the occurrence of mutations, the frequency of alleles and genotypes will remain constant over time. Such conditions are so restrictive that they are not likely to occur in nature. Even though genetic recombination is taken into account, mutations, gene flow between populations, and environmental changes influencing selection pressures on a population do not cease to occur in the natural world.

f. Students know how to solve the Hardy-Weinberg equation to determine the predicted frequency of genotypes in a population, given the frequency of phenotypes*.

The Hardy-Weinberg equilibrium equation can be used to calculate the frequency of alleles and genotypes in a population's gene pool. Where only two alleles for a trait occur in a

population, the letter *p* is used to represent the frequency of one allele and the letter *q* is used to represent the frequency of the other allele. Students should agree first that the sum of the frequencies of the two alleles is 1, and this is written $p + q = 1$. That is, the combined frequencies of the alleles account for all of the genes for a given trait. Students should then consider the possible combinations of alleles in a diploid organism. An individual could be homozygous for one allele ("pp") or homozygous for the other ("qq") or heterozygous (either "pq" or "qp"). These diploid genotypes will appear at frequencies that are the product of the allele frequencies, which is no more complicated than saying, for example, that the frequency of a diploid "pp" individual is (p^2) and the frequency of a diploid "qq" individual is (q^2). The heterozygotes are of two varieties, "pq" and "qp" (because the "p" allele might have been inherited from either parent), but the products of frequency pq and qp are the same, so the frequency of heterozygotes can simply be expressed as 2pq. The sum of the frequencies of the homozygous and heterozygous individuals must equal 1, since all individuals have been accounted for, and this us usually expressed as the equation $p^2 + 2pq + q^2 = 1$. The two equations discussed represent different statements. The first (p + q = 1) is an accounting of the two types of alleles in the population and the second ($p^2 + 2pq + q^2 = 1$) is an accounting of the three distinguishable genotypes. If the allele frequencies are known (for example, if p=0.1 and q=0.9) and Hardy-Weinberg equilibrium is assumed, then the frequencies p^2, $2pq$, and q^2 are respectively 0.01, 0.18, and 0.81. That is, 81% of individuals would be homozygous "qq". If we knew that p was a dominant (but non-selective) allele, then $p^2 + 2pq$ or 19% of the population would express the dominant phenotype of the p allele. The calculation can be used in reverse as well. If we assumed Hardy-Weinberg equilibrium conditions and knew that 81% of the population expressed the "qq" recessive phenotype, then the allele frequency q would be the square root of 0.81, and the rest of the terms could be calculated in a straightforward fashion.

Students can convince themselves of the state of equilibrium by constructing a Punnett Square that assumes random mating. The scenario might be a mass spawning of fish, where 100,000 eggs and sperm are mixed in a stream and meet up with each other randomly to form zygotes. The fraction of "p" and "q" type gametes in the stream can be calculated by thinking through the types of gametes produced by heterozygous and homozygous adult fish (for this exercise to work, the genotype distribution of adults must be in agreement Hardy-Weinberg equilibrium). With the frequencies or numbers of each type of zygote calculated in the cells of a Punnett Square, students will see that equilibrium is preserved. . Allele and genotype frequencies, which are the genetic structure of the study population, would remain constant for generations under the premise of Hardy-Weinberg equilibrium.

STANDARD SET 8: Evolution (Speciation)

Description of the Standards

8. Evolution is the result of genetic changes that occur in constantly changing environments. As a basis for understanding this concept:

a. Students know how natural selection determines the differential survival of groups of organisms.

Genetic changes can be the result of gene recombination during gamete formation and mutations. These events are responsible for variety and diversity within each species. Natural selection favors those individuals who are better suited to survive in a given environment. Those that are not well suited to the environment may die before they can pass on their traits to the next generation. As the environment continues to change, selection for adaptive traits is realigned with the change. Traits that were once adaptive may become disadvantageous in light of change. Students can explore the process of natural selection further with an activity based on predator-prey relationships. The main purpose of these activities is to simulate survival in predator or prey species as they struggle to find food or escape being consumed themselves. The traits of predator and prey individuals can be varied to test their selective fitness in different environmental settings.

An example of natural selection is the effect of industrial "melanism," or darkness of pigmentation, on the peppered moths of Manchester, England. These moths come in two varieties, one darker than the other, with the dark moth being rare prior to the industrial revolution while during the industrial revolution the light moth became rare. At the time of the industrial revolution, much coal was burned in the region, emitting soot and sulfur dioxide. For reasons not completely understood, the light colored moth variety was successfully adapted to the cleaner air conditions that existed in pre-industrial times and exist in the region today. However, the light-colored moth appears to have lost its survival advantage during times of heavy industrial air pollution. One early explanation was that when soot covered tree bark, light moths became highly visible to predatory birds. Once this happened, the dark peppered moth had an inherited survival advantage because it was harder to see against the sooty background. This may not have been the cause, and an alternative explanation is that the white peppered moth variety was more susceptible to the sulfur dioxide emissions of the industrial revolution. In any case, in the evolution of the moth, mutations of the genes resulted in light and dark moths, and through natural selection the light moth variety had an adaptive advantage until environmental conditions changed, giving the dark moths an advantage and resulting in the light moth becoming rare.

b. Students know a great diversity of species increases the chance that at least some species/organisms survive major changes in the environment.

This standard is similar to the previous standard set on diversity within a species, but takes student understanding one step further, addressing diversity among and between species. For the same reasons pertinent to intra-species diversity, increased diversity among species increases the chances that some species will be adapted to survive future environmental changes.

c. Students know the effects of genetic drift on the diversity of organisms in a population.

Genetic drift introduces a random pattern of evolution that is most likely to happen with small populations. If a random sample of individuals is geographically separated from the original small population, the gene frequencies of the random sample may not accurately reflect those of the original small population. The random sample could represent a significant deviation from the original population's gene pool. Consequently, the genetic drift from the original gene pool is not necessarily an adaptive change. There is no guarantee that a random shift in gene frequencies would make the next generation better adapted than before. The

bottleneck effect, nonselective population reductions due to disasters, and the founder effect, the colonization of a new habitat by a few individuals, describe situations that can lead to genetic drift of small populations.

d. Students know reproductive or geographic isolation affects speciation.

Events that lead to reproductive isolation of populations of the same species cause new species to appear. Reproductive barriers that prevent mating between populations through the isolation of habitats, breeding times and behaviors, genitalia, and gametes are called prezygotic (before fertilization). Postzygotic (after fertilization) barriers that prevent the development of viable, fertile hybrids exist because of genetic incompatibility between the populations, hybrid sterility, and hybrid breakdown. These isolation events can occur within the geographical range of a parent population (sympatric speciation) or when a small population becomes geographically isolated from its parent population (allopatric speciation). Sympatric speciation is much more common in plants than in animals, because of mistakes in cell division that result in polyploidy, or extra sets of chromosomes, that plants are able to pass on to hybrids. Polyploidy in animals is generally very deleterious or lethal in the long term because it interferes with sex determination, and animals, unlike most plants, are usually of one sex or the other. Allopatric speciation occurs in animal evolution as geographically isolated populations adapt to different environmental conditions. Also, the rate of allopatric speciation is faster in small populations than in large ones because of greater genetic drift.

e. Students know how to analyze fossil evidence with regard to biological diversity, episodic speciation, and mass extinction.

Analysis of the fossil record reveals the story of major events in the history of life on earth, sometimes called macroevolution, as opposed to the small changes in genes and chromosomes that occur within a single population, or microevolution. Explosive radiations of life following mass extinctions are marked by the four eras in the geological time scale: the Precambrian, Paleozoic, Mesozoic, and Cenozoic eras. The study of biological diversity from the fossil record is generally limited to the study of the differences among species rather than differences within a species. Biological diversity within a species is difficult to study because of the rarity of preserved organic material as a source of DNA in fossils.

Episodic speciation is most dramatic after the appearance of novel characteristics such as feathers and wings, or in the aftermath of a mass extinction that has cleared the way for new species to inhabit recently vacated adaptive zones. Extinction is inevitable in a changing world, but examples of mass extinction from the fossil record coincide with rapid global environmental changes. During the formation of the supercontinent Pangaea in the Permian period, most marine invertebrate species disappeared with the loss of their coastal habitats; during the Cretaceous period, a climatic shift to cooler temperatures because of diminished solar energy coincided with the extinction of dinosaurs.

f. Students know how to use comparative embryology, DNA or protein sequence comparisons, and other independent sources of data to create a branching diagram (cladogram) that shows probable evolutionary relationships.*

The area of study that connects biological diversity to phylogeny, or the evolutionary history of a species, is called systematics. Systematic classification is based on the degree of similarity between species. Thus, comparisons of embryology, anatomy, proteins, and DNA are used to establish the extent of similarities. Embryological studies reveal that ontogeny, development of the embryo, provides clues to phylogeny. In contrast to the old assertion that "ontogeny recapitulates phylogeny", (e.g., that it replays the entire evolutionary history of a species), structures such as gill pouches that appear during embryonic development but are less obvious in many adult life forms may establish homologies between species. These homologies are evidence of common ancestry. Likewise, homologous anatomical structures, such as the forelimbs of humans, cats, whales, and bats, are also evidence of a common ancestor. Similarity between species can be evaluated at the molecular level by comparing the amino acid sequences of proteins or the nucleotide sequences of DNA strands. DNA-DNA hybridization, restriction mapping, and DNA sequencing are powerful new tools of use in systematics.

Approaches for using comparison information to classify organisms based on evolutionary history differ greatly. Cladistics uses a branching pattern, or cladogram, based on shared derived characteristics to map the sequence of evolutionary change. The cladogram is a dichotomous tree that branches to separate those species that share a derived characteristic, such as hair or fur, from those species that lack the characteristic. Each new branch of the cladogram helps to establish a sequence of evolutionary history, however the extent of divergence between species is unclear from the sequence alone. Phenetics classifies species entirely on the basis of measurable similarities and differences with no attempt to sort homology from analogy. In recent years, phenetic studies have been helped by the use of computer programs to compare species automatically across large numbers of traits. Striking a balance between these two approaches to classification has often involved subjective judgements in the final decision of taxonomic placement. Students can study examples of cladograms and create new ones to understand how a sequence of evolutionary change based on shared derived characteristics is developed.

g. Students know how several independent molecular clocks, calibrated against each other and combined with evidence from the fossil record, can help to estimate how long ago various groups of organisms diverged evolutionarily from one other.*

Molecular clocks are another tool to establish phylogenetic sequences and the relative dates of phylogenetic branching. Based on the assumption that homologous proteins of different taxa, such as cytochrome *c*, and the genes that produce them evolve at relatively constant rates, the number of amino acid or nucleotide substitutions provides a record of change proportional to the time between evolutionary branches. When compared to branching times determined from the fossil record, the results from molecular clocks have generally been in agreement, but often the degree of molecular change has been a clearer indicator of divergence than the amount of morphological difference. By calibrating molecular change against the timeline set from the fossil record, phylogenetic branching dates can be estimated where gaps in the fossil record exist.

STANDARD SET 9: Physiology (Homeostasis)

Background

From the microscopic level of the cell to the total organism, each functioning unit is organized around the central theme of homeostasis, or how the body and its parts deal with changing demands while maintaining the constancy of internal environment. Over a century ago, noted French physiologist Claude Bernard (1859) described the difference between the internal environment of the cells and the external environment in which the animal lives. Organisms are shielded from the variations of the external environment by the 'constancy of the internal milieu.' This 'steady state' refers to the dynamic equilibrium achieved by the integrated functioning of all the parts of the organism, and was later termed homeostasis, which means "standing still," by American physiologist Walter Cannon. All organ systems of the human body contribute to homeostasis so that blood and tissue constituents and values stay within a normal range. Students will need supportive review (Grade 5, standard set 2; Grade 7, standard set 5) of the major systems of the body along with the organ components of these systems. As the prime coordinators of the body's activities, the nervous and endocrine systems must be examined and their interactive roles clearly defined.

Description of the Standards

9. As a result of the coordinated structures and functions of organ systems, the internal environment of the human body remains relatively stable (homeostatic), despite changes in the outside environment. As a basis for understanding this concept:

a. Students know how the complementary activity of major body systems provides cells with oxygen and nutrients and removes toxic waste products such as carbon dioxide.

The digestive system delivers nutrients (glucose) to the circulatory system. Oxygen molecules move from the air to the alveoli of the lungs, and then to the circulatory system. From the circulatory system, glucose and oxygen move from the capillaries into the cells of the body where cellular respiration occurs. During cellular respiration, these molecules are oxidized into carbon dioxide, water, and ATP energy. The process is reversed for the removal of carbon dioxide from its higher concentration in the cells, to the circulatory system, and finally its elimination by exhalation from the lungs. Students can trace the movement of oxygen molecules from the air, to the lungs, to the circulatory system. From the circulatory system, glucose and oxygen move from the capillaries into the extracellular fluid compartment, and from there into the cells of the body where cellular respiration takes place. This final cellular destination allows these molecules to be oxidized into carbon dioxide and water, with the energy of oxidation being captured in ATP. Students should also trace the diffusion of carbon dioxide from its higher concentration in the cells to the circulatory system, leading to its exhalation from the lungs,

The concentration of sugar in the blood is monitored, and students should know that sugar can be stored or pulled from reserves (glycogen) in the liver and muscles to maintain a constant blood sugar level. Amino acids contained in proteins also can serve as an energy source, but first the amino acids must be deaminated, or chemically converted, in the liver, producing a toxic product, which is converted to water-soluble urea and excreted by the kidneys. It should be emphasized that all of these chemicals are transported by the circulatory system and the cells. Organs at the final destination direct chemicals to their exit from the circulatory system.

b. Students know how the nervous system mediates communication between different parts of the body and the body's interactions with the environment.

The sense organs and other body receptors make us aware of the environment, for instance allowing for touch, taste, smell and collecting information about temperature, light, and sound. The body reflexively responds to external stimuli through a reflex arc (Grades 9-12, Biology, Standard Set 9e). Students can examine the sense organs, identify other body receptors that make them aware of their environment, and see how the body reflexively responds to an external stimulus through a reflex arc. Hormones work in conjunction with the nervous system, as for example in the digestion system, where insulin released from the pancreas into the blood regulates the uptake of glucose by cells. The pituitary master gland produces growth hormone for controlling height. Other pituitary hormones such as follicle-stimulating hormone (FSH) and luteinizing hormone (LH) control the gonads; thyroid stimulating hormone (TSH) controls the thyroid; and adrenocorticotropic hormone (ACTH) regulates the formation of glucocorticoids by the adrenal cortex. This master gland is itself controlled by the hypothalamus of the brain.

c. Students know how feedback loops in the nervous and endocrine systems regulate conditions in the body.

Feedback loops are the means by which the nervous system uses the endocrine system to regulate body conditions. The presence or absence of hormones in blood brought to the brain by the circulatory system will trigger an attempt to regulate body conditions. Feedback loops can be made relevant by discussing the hormone leptin, which is produced by fat cells as they become filled with storage reserves. Leptin is carried by the blood to the brain where it normally acts to inhibit the appetite center, an example of negative feedback. When fat reserves diminish, the concentration of leptin decreases, which in turn causes the appetite center in the brain to start the hunger stimulus and activate the urge to eat.

d. Students know the functions of the nervous system and the role of neurons in transmitting electrochemical impulses.

Transmission of nerve impulses is mediated by a sodium and potassium ion concentration gradient across a membrane that is used during the generation of an electrochemical impulse called an action potential. The gradient is restored by an active transport system; a pump that exchanges sodium and potassium ions across the membrane and uses ATP hydrolysis as a source of energy. The release of neurotransmitter chemicals from the axon terminal at the synapse may initiate an action potential in an adjacent neuron, propagating the impulse to a new cell.

e. Students know the roles of sensory neurons, interneurons, and motor neurons in sensation, thought, and response.

The pathways of impulses from dendrite to cell body to axon of sensory neurons, interneurons, and motor neurons link the chains of events that occur in a reflex action. Students should be able to diagram this pathway. Similar paths of neural connections lead to the brain

where the sensations become conscious, and conscious actions are initiated in response to external stimuli. Students might also trace the path of the neural connections as the sensation becomes conscious and a response to the external stimulus is initiated. Students should also be able to identify gray and white matter in the central nervous system.

f. Students know the individual functions and sites of secretion of digestive enzymes (amylases, proteases, nucleases, lipases), stomach acid, and bile salts.*

Secretions of enzymes are mixed with food from the mouth to the stomach and through the small intestines to bring about digestion. For example, salivary glands and the pancreas secrete amylase enzymes that change starch into sugar. Stomach acid and gastric enzymes begin the process of the breakdown of protein that is continued by intestinal and pancreatic secretions. Lipase enzymes secreted by the pancreas break down fats and fatty acids. Bile secreted by the liver furthers the process of digestion emulsifying fats and facilitating lipid digestion. Students might diagram the digestive tract, labeling important points of secretion and tracing the pathways from digestion of starches, proteins and other foods. They can then outline the role of the kidney nephron in the formation of urine, and the role of the liver in glucogenesis and glycogenolysis (glucose balance), and in blood detoxification.

g. Students know the homeostatic role of the kidneys in the removal of nitrogenous wastes and the role of the liver in blood detoxification and glucose balance.*

Microscopic nephrons within the kidney filter out body wastes, regulate water and stabilize electrolyte levels in blood. The liver removes, stores and excretes toxic materials from the blood while regulating blood glucose.

h. Students know the cellular and molecular basis of muscle contraction, including the roles of actin, myosin, Ca^{+2}, and ATP.*

Actin and myosin filaments in a sarcomere generate movement in stomach muscles as controlled by calcium ions and ATP. Striated muscle fibers reflect the filamentous makeup and contraction state evidenced by their banding patterns. A sketch of the sarcomere can be used to indicate the functions of the actin and myosin filaments, and the role of calcium ions and ATP in muscle contraction.

i. Students know how hormones (including digestive, reproductive, osmoregulatory) provide internal feedback mechanisms for homeostasis at the cellular level and in whole organisms.*

Hormones act as chemical messengers, affecting the activity of neighboring cells or other target organs. Their movement can be traced from their point of origin to the target site. The feedback mechanism works to regulate the activity of hormones and promotes homeostasis.

STANDARD SET 10: Physiology (Infection and Immunity)

Background

Some bacteria, parasites, and viruses cause human diseases because they either rob the body of necessary sustenance or secrete toxins that cause injury. The human body has a variety of mechanisms to interfere with or destroy invading pathogens. Besides protection afforded by the skin, one of the most effective means of defending against harmful body attackers is the immune system with its cellular and chemical defenses. Students should develop a clear understanding of the components of the immune system, and know how vaccines and antibiotics are used. They should also know that AIDS is a disease that leads to compromising of the immune system, with the result that affected individuals can succumb to other AIDS (Acquired Immune Deficiency Syndrome) infections that are harmless to individuals with an intact immune system.

Description of Standards

10. Organisms have a variety of mechanisms to combat disease. As a basis for understanding the human immune response:

a. Students know the role of the skin in providing nonspecific defenses against infection.

The skin serves as a physical barrier to the passage of many disease causing microorganisms. Cuts and abrasions compromise the barrier effect of the skin. Charts and overhead projections can be used to show the dangers and physiologic responses of a break in the skin barrier.

b. Students know the role of antibodies in the body's response to infection.

Antibodies are produced by cells in opposition to antigens, which are "foreign" to the body. An example of an antigen might be a surface protein of a flu virus, which is unlike any human proteins in its shape and structure. The immune system recognizes that the flu virus structure is different, and generates proteins called antibodies that bind to the flu virus. Antibodies can inactivate pathogens directly or signal immune cells to their presence.

c. Students know how vaccination protects an individual from infectious diseases.

It takes several weeks for the immune system to develop immunity to a new antigen, and vaccinations are a way of safely giving the body a look at the foreign structures "in advance". Vaccines usually contain either weakened or killed pathogens that are responsible for a specific infectious disease, or a purified protein or subunit from the pathogen. Although the vaccine does not cause an infectious disease, the antigens in the mixture prompt the body to generate antibodies in opposition to the pathogen. When the individual is exposed to the actual pathogenic agent, perhaps years later, the body still remembers having seen the antigens in the vaccine dose and can quickly respond. Students have been exposed to the practical aspects of immunity through their knowledge of the vaccinations they must receive as a prerequisite to entering school. They have all experienced 'shots,' and may have seen their personal vaccination record in which dates and kinds of inoculation are recorded. The review of a typical vaccination record, focusing on the reason for the shots and how they work, may serve as an

effective entry to the subject.

Students should review the history of vaccine usage. Descriptions of vaccine usage from pragmatic exposure are available in ancient literature, but the term itself is derived from the cowpox exudate that was used by Edward Jenner in the 1700's to inoculate villagers against the more pathogenic smallpox. Louis Pasteur developed several vaccines and is noted for the rabies treatment. Poliovirus, the cause of infantile paralysis, was finally conquered in the 1950's through vaccines refined by Jonas Salk and Albert B. Sabin.

d. Students know there are important differences between bacteria and viruses with respect to their requirements for growth and replication, the body's primary defenses against bacterial and viral infections, and effective treatments of these infections.

A virus is the simplest form of a genetic entity and is incapable of metabolic "life" and reproduction outside the cells of other living organisms. A virus contains genetic material, but has no ribosomes. Although some viruses are benign, many harm their host organism by destroying or altering host cell structures. Generally, the body perceives viruses as antigens and produces antibodies to counteract the virus. Bacteria are organisms with a full cellular structure. They, too, can be benign or harmful. Harmful bacteria and their toxins are perceived as antigens by the body which in turn produces antibodies. Infectious diseases may be treated with antiseptics, which are chemicals that oxidize or in other ways inactivate the infecting organism. Antibiotics are effective in treating bacterial infections, sometimes working by destroying or interfering with the growth of bacterial cell walls or cell wall physiology. Antibiotics are ineffective in treating virus infections.

Students might research infections caused by protists (malaria, amoebic dysentery), bacteria (blood poisoning, botulism, food poisoning, tuberculosis), and viruses (rabies, colds, influenza, AIDS). They might also investigate the pathogens currently being discussed in the media and study each infectious organism's requirements for growth and reproduction. Teachers should review the dangers of antibiotic resistance of common bacteria through long-standing over-application as shown by the increasing incidence of drug-resistant TB and other bacteria. Using a commercially available kit, it is possible to demonstrate how antibiotics may act generally or specifically against bacteria. Agar plates may be inoculated with different bacteria and different antibiotic discs placed on these plates to create a clear zone of growth inhibition around the antibiotic discs**.**

e. Students know why an individual with a compromised immune system (for example, a person with AIDS) may be unable to fight off and survive infections by microorganisms that are usually benign.

When an immune system is compromised (e.g., through infection by the human immunodeficiency (HIV) virus), it either becomes unable to recognize a dangerous antigen or incapable of mounting an appropriate defense. This happens when the virus infects and destroys key cells in the immune system.

f. Students know the roles of phagocytes, B-lymphocytes, and T-lymphocytes in the immune system*.

Phagocytes move, amoeba-like, through the circulatory system consuming waste and foreign material, such as aged or damaged blood cells and some infectious bacteria and viruses. Two types of lymphocytes, or white blood cells, are produced in bone marrow and travel through the circulatory system. T-lymphocytes move to the thymus gland and develop "cytotoxic" (cell killing) or "helper" functions in the immune system. The cytotoxic T-cells are particularly useful for surveillance of pathogens that are intracellular. The intracellular pathogen cannot be reached by antibodies, because of the cell membrane, but the infected cell can be identified and killed. Helper T-cells help to organize both the cellular and humoral immune responses. B-lymphocytes generate antibodies (humoral immunity) that can bind to foreign antigens, with each cell only producing one type of antibody.